In the Specification

Page 1, line 28 - page 2, line 19:

One possibility of stall-detection for stepper motors is described in EP-A2-0046722. The actual movement of the stepper motor rotor in response to the ~~energising~~ energizing of the motor stator windings by excitation signals presented in each step interval of the motor is detected. This is done by measuring the amplitude of the voltage signal induced in a ~~non-energised~~ non-energized stator winding as a result of the presentation of the excitation signals to the ~~energised~~ energized stator windings, both in a present step interval and in an immediately preceding step interval. The physics behind the stall detector in the above document is related to the operation of a transformer: a primary coil (active motor winding) generates a magnetic flux which generates in a secondary coil (inactive motor winding) an induced voltage. In case the motor is able to rotate, the magnetic coupling between the coils is small, and there is a small residual magnetic field energy. In case, however, the rotor is blocked, the residual magnetic field energy is larger, hence the secondary coil shows an increased induced voltage. An induced voltage amplitude which exceeds a threshold indicates a failure of the rotor to respond to the newly ~~energised~~ energized stator windings and may be used as an indication of failure in the motor. This known device works on the principle of current/voltage signals appearing on a ~~non-energised~~ non-energized coil (at the beginning of the ~~non-energised~~ non-energized phase) as a result of ~~energising~~ energizing another coil. In as much as the first decay pulse has died out, or on top of the remaining signal, the back emf (for higher rotation speeds) is measured. The principle described is sensitive to supply voltage, because the amplitude of the primary coil varies with supply voltage.

Page 3, line 6 - page 4, line 9:

The present invention provides an apparatus for detecting rotation of a rotor of a multiple phase motor with bipolar drive, excluding a three-phase motor with bipolar drive with star connected coils or motor stator windings, the motor comprising at least a first and a second ~~energisable~~ energizable motor stator winding. The invention is not limited to two-phase motors. The motor may for example be a stepper motor, either with a micro-stepping driving or not, or a brushless DC motor. The apparatus comprises means for sequentially and alternately sensing a back electromagnetic force (back EMF or BEMF or bemf) on the first and the second motor stator winding at or near a ~~non-energised~~ non-energized state thereof. With at or near the end is

meant during the last 50% of the period of the ~~non-energised~~ non-energized state, preferably during the last 25%, more preferred during the last 10% and still more preferred during the last 5% of the period of the ~~non-energised~~ non-energized state. A motor stator winding is ~~non-energised~~ non-energized if no driving current is applied to that motor stator winding by a driving mechanism. Therefore, a ~~non-energised~~ non-energized motor stator winding is substantially current free (or substantially current-less or in a substantially current-zero state): some current may however be flowing in that ~~non-energised~~ non-energized winding, which is then current generated by the bemf or by a decay of the winding.

In the present invention the voltage or back electromagnetic force over a ~~non-energised~~ non-energized motor stator winding is observed, preferably as late as possible in the ~~non-energised~~ non-energized phase, where this voltage is a measure of a rotation speed, after the disappearance of an ~~energising~~ energizing pulse or signal on another motor stator winding.

The means for sensing the back electromagnetic force may comprise timing means for controlling the sensing of the back electromagnetic force on the first respectively second motor stator winding so as to occur during ~~energising~~ energizing of the second respectively first motor stator winding.

The sensing may have a fixed or adjustable relative position in a ~~non-energised~~ non-energized state time window. The back electromagnetic force may be sensed based on the timing means. A memory device may be provided for storing the sensed back electromagnetic force. Multiple samples of the back electromagnetic force may also be made based on the timing means, the multiple samples being stored as a combined value, e.g. a mean value, in the memory device or as separate values in a plurality of memory devices. The plurality of samples may thus be stored as such on a memory device, or as processed values.

Page 4, line 20 - page 5, line 2:

An apparatus according to the present invention may comprise means for connecting one terminal of a ~~non-energised~~ non-energized motor stator winding to a fixed or reference potential and means for at the same time measuring the voltage at an other terminal of that ~~non-energised~~ non-energized motor stator winding, thus measuring a unipolar signal across one ~~non-energised~~ non-energized motor stator winding for sensing the voltage.

The present invention also provides a method for detecting rotation of a rotor of a multiple phase motor with bipolar drive, excluding a three-phase motor with bipolar drive with

star connected coils or motor stator windings, the motor comprising at least a first and a second ~~energisable~~ energizable motor stator winding. The method comprises sequentially and alternately sensing a voltage on the first and the second motor stator winding at or near a ~~non-energised~~ non-energized state thereof. With at or near the end is meant during the last 50% of the period of the ~~non-energised~~ non-energized state, preferably during the last 25%, more preferred during the last 10% and still more preferred during the last 5% of the period of the ~~non-energised~~ non-energized state.

The sensing of the voltage on the first respectively second motor stator winding may be carried out during ~~energising~~ energizing of the second respectively first motor stator winding. The motor may be driven in microstepping operation.

The sensing may have a fixed or adjustable relative position in a ~~non-energised~~ non-energized state time-window.

Page 5, lines 16-21:

For sensing the voltage a unipolar signal may be measured across one ~~non-energised~~ non-energized motor stator winding by connecting one terminal of the motor stator winding to a fixed or reference potential while measuring the voltage at an other terminal of that ~~non-energised~~ non-energized motor stator winding. Alternatively, a differential voltage may be measured. A method according to the present invention is compatible with both measurement techniques.

Page 6, lines 14-16:

Fig. 3 is a current-vector representation of four available observation points in time with one of the coils of the two-phase micro-stepping motor with bipolar drive being ~~non-energised~~ non-energized.

Page 6, lines 25-26:

Fig. 10 illustrates back EMF signals sampled at zero currents (~~non-energised~~ non-energized state) being used as a speed indication.

Page 7, line 31 - page 8, line 7:

A drive current IA flowing from a first terminal a of the first winding 3 to a second terminal b thereof causes the first stator pole, e.g. top stator pole, to be a south pole while the second stator pole, e.g. bottom stator pole, is a north pole. This attracts the rotor 2 in the position shown. If the power to the first motor winding 3 is removed and the second motor winding 4 is ~~energised~~ energized, i.e. a drive current IB is flowing from a first terminal c of the second winding 4 to a second terminal d thereof, the rotor 2 will turn over 90 degrees, or one step. This 90 degrees turn is an electrical 90 degrees turn and can be implemented in the stepper motor as a 90/M physical turn, depending on the numbers of N/S pole pairs.

Page 8, lines 29-32:

The micro stepper can also work as a simple stepper motor where electrically always 90 degree turns are made (Full stepping). Also in full-stepping the above principle will work, however the energy decay in the coil can make that the BEMF becomes more difficult to detect.

Page 9, line 9 - page 10, line 2:

When the current IA through the first winding 3 is for example maximal, at the same time the second winding 4 is ~~non-energised~~ non-energized, and the current through the second winding 4 is zero, as can be seen in parts (b) and (c) of Fig. 1. Due to the current IA through the first winding 3, the rotor 2 turns so as to align with the magnetic field created by the current IA through the first winding 3. The rotor 2 is thus a turning or rotating magnet, and this rotating magnet generates a moving magnetic field. Hence, there are two synchronous fields inside the motor, i.e. the stator field induced by the coil current and the rotor field, which is the magnetic field around the rotating rotor 2. The difference in alignment between these two fields or between the rotor flux and the stator flux is called the load angle.

The second winding 4 picks up the moving magnetic field of the rotor 2, and although it is ~~non-energised~~ non-energized, no current is sent through this second winding 4 by a driving mechanism, a back EMF voltage signal is visible across the first and second terminals c, d of the second winding 4. Observation of the back EMF signals can only be done at a limited number of observation points in time, more particularly at each winding 3, 4 when it is ~~non-energised~~ non-energized, or thus when the drive current through the particular winding 3, 4 has a zero-crossing.

For the example of a two-phase bipolar stepper motor as given above, observation of the back EMF signals can be done at the first winding 3 at a moment t1 (see Fig. 1(b)), when the drive current IA is zero and the drive current IB is maximal, at the second winding 4 at a moment t2 (see Fig. 1(c)), when the current IB is zero and the current IA is minimal (or maximal negative), at the first winding 3 at a moment t3, when the current IA is zero and the current IB is minimal (or maximal negative) and at the second winding 4 at a moment t4, when the current IB is zero and the current IA is maximal.

Page 10, lines 9-27:

An optimised sensing time (or sampling time) can be chosen, as a function of the motor construction parameters, the expected rotor speed and the shape of the applied coil-currents. Fast moving rotors in combination with high coil-currents require back EMF sampling at or near the end of the ~~non-energised~~ non-energized or substantially current-less state of the coil, or even multiple samples during the ~~non-energised~~ non-energized state. With at or near the end is meant during the last 50% of the period of the ~~non-energised~~ non-energized state, preferably during the last 25%, more preferred during the last 10% and still more preferred during the last 5% of the period of the ~~non-energised~~ non-energized state. If multiple samples are taken during the ~~non-energised~~ non-energized state, for example a first sample may be taken during the first 10% of a period of the ~~non-energised~~ non-energized state, a second sample may be taken at between 40% and 60% of that period, and a third sample may be taken during the last 10% of the period of the ~~non-energised~~ non-energized state. Taking more than 3 samples during a period of the ~~non-energised~~ non-energized state may be preferred, and these samples may be, but do not need to be, spread equally over a period of the ~~non-energised~~ non-energized state. Motor construction parameters influence the amplitude and shape of the bemf signals as well as the overall magnetic situation inside the motor. For a given motor and a known applied coil current, the influence of these can be removed using calibration techniques.

Page 11, line 29 - page 12, line 11:

Fig. 3 is a current-vector representation of the four available observation points t1, t2, t3, t4 in time, with one of the coils being ~~non-energised~~ non-energized. Time is represented by a vector which rotates anti-clockwise around an origin. Projection of the time vector on the orthogonal axes IcoilA and IcoilB gives the amplitudes of the drive currents IA and IB through

the first and second windings 3, 4 respectively. As can be seen from Fig. 3, at a moment t1, the drive current IA through the first winding 3 is zero, thus the first winding 3 is ~~non-energised~~ non-energized, and the drive current IB through the second winding 4 is maximal. At that moment, the back EMF voltage over the first winding 3 can be measured. At a moment t2, the drive current IA through the first winding 3 is maximal negative, and the drive current IB through the second winding 4 is zero, or thus the second winding 4 is ~~non-energised~~ non-energized. At that moment t2, the back EMF voltage over the second winding 4 can be measured. As the drive currents IA and IB are applied by the user, their phase is exactly known, and thus the moments t1, t2, t3, t4 at which any of the windings 3, 4 is ~~non-energised~~ non-energized (or thus has a drive current signal IA, IB which equals zero) is exactly known.

Page 14, lines 13-27:

Fig. 5 is a schematic representation of digital processing of the back EMF signals. The circuit represented in Fig. 5 comprises a selection and sampling circuit 25 for selecting at which terminals the back EMF voltage value is to be captured, and for sampling that value, thus generating a signal 26 corresponding to a measured back EMF value. The selection and sampling circuit 25 receives timing signals for doing the sampling at the right moments in time as explained above, i.e. at those moments in time when any of the windings 3, 4 are in a ~~non-energised~~ non-energized state. The circuit required for doing this is comparable to multiplexing switch 10 in Fig 4, in front of an ADC. The measured back EMF value signal 26 is fed to an analog-to-digital converter (ADC) 27, where it is converted into a digital value 28. This digital value 28 is then digitally processed in a digital processing unit 29 to which parameters 30 are fed. The output of the digital processing unit 29 is a signal 31 indicative for rotor movement, this rotor movement including for example speed and/or acceleration.

Page 16, lines 14-15:

Fig. 8(c) illustrates the sampling clock for digital filter 24.Fig. 8(d) illustrates the unfiltered output signal 33.